RESEARCH MEMORANDUM

AN NACA TRANSONIC TEST SECTION WITH TAPERED SLOTS TESTED AT MACH NUMBERS TO 1.26

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AN NACA TRANSONIC TEST SECTION WITH TAPERED SLOTS TESTED AT MACH NUMBERS TO 1.26

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SUMMARY

An NACA octagonal transonic slotted test section has been modified to include slots with point origins located at the tunnel aerodynamic minimum and which diverged linearly over a length of $1\frac{1}{2}$ jet diameters. The uniformity of the supersonic flow along the axis of this configuration was investigated and an indication of interference effects on a body of revolution was obtained.

Pressure distributions along the axis and one wall of this slotted configuration are presented and indicate the attainment of a test region with satisfactorily uniform Mach number distributions throughout the supersonic Mach number range from 1.0 to 1.26. The supersonic Mach number in this range can be varied continuously merely by varying the power.

Pressure distributions over a relatively large nonlifting body of revolution in this slotted test section when compared with similar measurements obtained in an essentially interference-free large closed wind tunnel indicated a reasonable agreement over most of the model surface at subsonic and transonic Mach numbers up to 1.08. At greater test Mach numbers, disturbances believed to be due to shock reflections associated with the body bow wave appeared at the surface of the model.

INTRODUCTION

The attainment of supersonic flows in an NACA transonic test section was first reported in reference 1. Supersonic velocities were established in this slotted test section by merely increasing the pressure difference across the slotted test section; the supersonic flow when once established could be varied continuously by varying this pressure difference. The pressure distributions along the axis of the slotted test section appeared fairly satisfactory within the range of test-section Mach numbers from 1.0 to 1.1 with variations in Mach number not exceeding ±0.025. As the Mach number is increased above 1.1, the axial distribution of pressure becomes progressively less satisfactory, and at a test-section Mach number of 1.27 variations in Mach number of ±0.05 occurred within the length of the test section. These pressure distributions were also characterized by a rapid initial expansion to the test-section Mach number. The effective nozzle length necessary to initially expand the flow to the test-section Mach number in this rectangular-slot configuration was of the order of 1/2 jet diameter.

This investigation was conducted in an attempt to establish more uniform supersonic flows along the axis of an NACA transonic test section than had previously been obtained. At the same time the favorable characteristics of the original slotted test section (reference 1), that is, the continuously variable supersonic Mach number, the beneficial reduction of solid blockage interference effects, and the elimination of choking were to be maintained.

A possible approach to the attainment of improved axial pressure distributions in the low supersonic Mach number range up to 1.27 appeared to be the reduction of the rapid initial expansion associated with the short effective nozzle length in the rectangular-slot configuration. In an effort to increase the length of the effective nozzle, it was considered that the introduction of long tapered slots originating at a point might result in a more gradual expansion of the flow to the test-section Mach number.

Based on this approach a slot which originated at a point and diverged linearly for $1\frac{1}{2}$ jet diameters was incorporated into an NACA transonic test section. Axial pressure distributions along the tunnel wall and center line were obtained through a continuous Mach number range up to 1.26 with the test section empty. Further tests, similar to those conducted in reference 1, in which a relatively large prolate spheroid was used as a model, were made to investigate tunnel-wall interference associated with the divergent slot throughout the speed range up to a Mach number of 1.2.

SYMBOLS

The following symbols are used in presenting the results of this investigation:

a	velocity of sound in air
D	effective diameter of tunnel (diameter of circle with area equal to that of tunnel cross section)
H	absolute total pressure
l	body length
M	stream Mach number (V/a)
M_o	stream Mach number at midpoint of model location, tunnel empty
M_F	stream Mach number at nose position of body, tunnel empty
M_R	stream Mach number at tail position of body, tunnel empty
p	absolute static pressure
$(p/H)_{cr}$	critical pressure ratio $(M = 1.0)$
S	distance from midpoint of test section along tunnel longitudinal axis
S'	distance from origin of slot along tunnel longitudinal axis
V	stream velocity
x	axial distance from nose of body

APPARATUS AND METHODS

A 12-inch effective-diameter octagonal slotted test section similar to the test section described in reference 1 was used for the present study. The test section had a length-diameter ratio of 2 and was surrounded by a tank whose diameter was twice the jet diameter. Eight axial slots were located at the corners between the flat sides. The slots had point origins located at the aerodynamic minimum and diverged linearly for $1\frac{1}{2}$ jet diameters, downstream of which station the slots maintained nearly constant width, such that one-eighth of the total periphery remained open. Because of physical limitations the $1\frac{1}{2}$-jet-diameter divergent slot was selected as the maximum length divergent slot for this tunnel configuration. The slots were continued approximately 1 jet diameter into the diffuser such that the flats between the slots maintained constant width. The cross-sectional area at the downstream end of the slots was approximately 20 percent greater than that at the aerodynamic minimum. A longitudinal schematic diagram and a scaled cross-sectional view of the slotted region are presented in figure 1.

The test model was a $1\frac{1}{3}$-inch-diameter prolate spheroid of fineness ratio 6 (reference 1). The orifice locations on the model are presented in figure 2.

The local static pressures along the test section center line were obtained by means of orifices in a $\frac{3}{8}$-inch-diameter axial tube extending upstream through the test section to the entrance bell. Pressures along the longitudinal center line of a tunnel flat and along the tank wall were recorded simultaneously with the pressures along the test-section center line. The tunnel air-stream Mach number was calibrated over the entire speed range by using as a reference the pressure measured at a single orifice located in the tank near the upstream end of the slotted region. The total pressure of the air stream was obtained in the settling chamber upstream of the entrance cone.

Model pressures were recorded simultaneously with the calibrated free-stream Mach number and were not corrected for existing axial pressure variations noted in the model test region. For comparison, an essentially interference-free test of the model was obtained in the Langley 8-foot high-speed tunnel (reference 1).

Schlieren studies of the tunnel-empty configuration were made with a conventional single-path, parallel-light, schlieren system utilizing 12-inch-diameter parabolic-mirror surfaces and a light source producing flashes of approximately 10 microseconds duration.

RESULTS AND DISCUSSION

The axial pressure distributions along the center line and wall of a 12-inch-effective-diameter octagonal transonic slotted test section, utilizing a rectangular-shaped slot as reported in reference 1, are shown in figure 3.

Figure 4 presents similar pressure distributions in the slotted test section with the pointed divergent slots $1\frac{1}{2}$ jet diameters in length. Also included are pressure distributions along the tank wall.

The maximum axial Mach number variation over a region 2/3 jet diameter in length corresponding to the model location in the slotted test section employing the rectangular-slot configuration (fig. 3) was approximately ±0.022 at a free-stream Mach number of 1.08 and increased in magnitude to ±0.053 at a free-stream Mach number of 1.27. Mach number variations are likewise presented in table I for the entire test Mach number range in the slotted test section with pointed divergent slots $1\frac{1}{2}$ jet diameters in length. A maximum Mach number variation of ±0.008 was indicated in the transonic Mach number range up to 1.05. In the low supersonic Mach number range between 1.05 and 1.24, the maximum Mach number variation is ±0.015 and increases to ±0.018 at the limiting test Mach number of 1.266. Although the axial pressure distributions in the rectangular-slot configuration appeared fairly satisfactory up to a Mach number of 1.1, an appreciable improvement in axial-flow uniformity is shown for the divergent-slot configuration in this Mach number range. In addition, the range of satisfactorily uniform axial pressure distributions is extended to a Mach number of 1.26.

Schlieren photographs of the flow in the transonic slotted tunnel with the divergent slots are presented throughout the Mach number range from 0.99 to 1.26 in figure 5. The $\frac{3}{8}$-inch-diameter axial static survey tube is shown in position. The longitudinal location of the schlieren field is designated in figure 4. The photograph at Mach number 0.0 (fig. 5(a)) shows only existing striae in the schlieren windows. While these striations complicate the photographs, an indication of relative density changes and disturbances can be noted. At a Mach number of 0.999 (fig. 5(b)), the schlieren field appears to be free of disturbances. As the Mach number is increased to 1.028 (fig. 5(c)), several weak normal disturbances appear at the upstream end of the slotted region. These disturbances are associated with a slight rise in static pressure ratio corresponding to 0.008 in Mach number as noted in figure 4. A partial transition of these weak normal disturbances into multiple weak oblique waves occurs as the Mach number is increased to 1.048 (fig. 5(d)). These oblique disturbances do not appear to originate at the point origin of the slot. Further increases in Mach number (figs. 5(e) to 5(l)) indicate complete transition to multiple oblique disturbances which remain extremely weak, substantiating the trends of the flow along the axis of the tunnel indicated in figure 4.

The investigation of the long divergent slot in an NACA transonic test section indicated that the rapid rate of expansion to the test-section Mach number in the rectangular-slot configuration was considerably reduced. At a Mach number of 1.27, the expansion occurs over an effective nozzle length of approximately $1\frac{1}{4}$ jet diameters in the divergent-slot configuration and slightly more than $\frac{1}{2}$ jet diameter in the rectangular-slot configuration (figs. 3 and 4). This decrease in rate of flow expansion was associated with an appreciable reduction of the compression region following the initial expansion present in the rectangular-slot configuration.

Satisfactory agreement between tunnel center-line and wall pressure distributions is indicated for the portion of the slotted test section immediately following the effective nozzle region in the divergent-slot configuration (fig. 4). Tank-wall pressure distributions also shown in this figure remain uniform at all test Mach numbers.

The similarity of limiting Mach numbers in both tunnel configurations is believed to result from duplicate area ratios at the station where the slots fair into the solid portion of the diffuser. The longitudinal pressure distributions, shown in figure 4, along the tunnel center line and wall indicate that a strong disturbance moves downstream in the slotted portion of the diffuser as the supersonic test Mach number is increased. At the limiting test Mach number of 1.26, this disturbance appears to be located at a downstream station where the tunnel cross section is essentially closed. The pressure distributions also show a local decrease in the static pressure ratio which occurs over a rear portion of the slotted test region. This decrease is believed to result from the short faired transition section of the tunnel wall between the slotted test section and the slotted diffuser necessary because of the introduction of the long divergent slot entrance into the fixed-length slotted test section.

The horsepower required for the divergent-slot configuration did not exceed that reported in reference 1 for the rectangular-slot configuration. As the primary purpose of this investigation was confined to the establishment of axially uniform supersonic flows, no particular effort was made to obtain optimum power performance.

Figure 6 presents the measured pressure distributions over the $1\frac{1}{3}$-inch-diameter prolate spheroid at zero angle of attack in the transonic slotted tunnel employing divergent slots in comparison with similar pressure distributions obtained in the 8-foot-diameter circular closed tunnel for several Mach numbers. These pressure-distribution comparisons are similar to those obtained with the same body in the rectangular-slot configuration of reference 1. The pressure distributions over the test body mounted in the 8-foot tunnel are regarded as essentially interference-free since the ratio of cross-sectional area of body to cross-sectional area of tunnel is 0.00019. These pressure distributions were obtained throughout the subsonic Mach number range to 0.99 and at a supersonic Mach number of 1.2 (reference 1). Additional supersonic Mach numbers were obtained between 1.02 and 1.2 by moving the test body upstream into the supersonic nozzle of the 8-foot tunnel where a positive Mach number increment of approximately 0.03 existed over the model. The Mach numbers at the nose position of the body were used for the comparison in this Mach number range.

A Mach number calibration in the slotted tunnel, based upon the tank pressure at the upstream end of the tank, was used to indicate air-stream Mach number at a location in the test section corresponding to the mid-point position of the test body. The pressures over the test body were not corrected for the existing axial pressure gradients that are shown in figure 4. The forward portion of the model extended over the down-stream end of the divergent slotted region approximately 1/3 jet diameters so that the ratio of open to total peripheries of the tunnel opposite the nose of body was approximately one-tenth.

The pressure distributions over a large portion of the body show good agreement for the two tunnel configurations at subsonic Mach numbers not greatly exceeding the critical and fair agreement over most of the model surface at Mach numbers up to 1.08. This includes a large portion of the Mach number range between 0.88 and 1.13, through which this body could not possibly be tested in a closed tunnel of equal size because of choking. Above a Mach number of 1.08, a pressure rise relative to the pressure distributions obtained in the Langley 8-foot high-speed tunnel appears over the forward part of the body and moves rearward with increasing Mach number. At a Mach number of 1.20, the pressure rise occurs at about the 65 percent body station. This pressure rise appears to correspond to reflected shock waves associated with the body bow wave indicated in reference 1 and by other schlieren observations not included in this report. The pressures over the body rearward of these non-uniformities fall below the pressures obtained in the 8-foot-tunnel tests. A pressure rise also occurs over the rear 30-percent portion of the body for a test Mach number of 1.020 and appears to indicate a difference of shock movement with test Mach number similar to that reported in reference 1. The positive Mach number increment of approximately 0.03 over the body in the 8-foot tunnel at this low supersonic Mach number tends to exaggerate the aforementioned pressure difference.

This investigation has demonstrated the feasibility of establishing reasonably uniform supersonic flows in a slotted test section through a continuously variable Mach number range up to 1.26, while at the same time indicating a beneficial reduction of solid blockage interference and the elimination of choking which were first reported in reference 1. Although reasonably uniform axial Mach number distributions can be obtained in this slotted configuration, tests on a body of revolution indicate that before these uniform flows can be completely utilized for tests of relatively large models, disturbances over the model, apparently caused by shock reflections associated with the model bow wave must be reduced or eliminated. The pointed $1\frac{1}{2}$-jet-diameter linear-divergent slot configuration employed in the octagonal transonic test section does not necessarily include the optimum divergent slot length or plan form, but of a number of slot configurations investigated, it has produced the most nearly uniform velocity distributions in the transonic speed range.

CONCLUSIONS

The results of an investigation in the NACA 12-inch octagonal slotted transonic test section employing pointed linearly divergent slots $1\frac{1}{2}$ tunnel diameters in length indicate the following conclusions:

1. A model test region with satisfactorily uniform Mach number distributions can be obtained in this slotted test section throughout the supersonic Mach number range from 1.0 to 1.26, and the supersonic Mach number can be varied continuously merely by varying the power.

2. A beneficial reduction of interference effects due to solid blockage and the elimination of choking are obtainable in this configuration on a relatively large nonlifting body of revolution through the Mach number range to 1.08.

3. Further investigation to eliminate or alleviate disturbances over test models apparently caused by shock reflections is necessary before the uniform supersonic flows in this slotted configuration can be completely utilized for tests of relatively large models.

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REFERENCE

1. Wright, Ray H., and Ward, Vernon G.: NACA Transonic Wind-Tunnel Test Sections. NACA RM L8J06, 1948.

TABLE I

AXIAL MACH NUMBER VARIATION OVER MODEL TEST REGION IN NACA TRANSONIC TEST SECTION WITH POINTED $1\frac{1}{2}$-JET-DIAMETER DIVERGENT SLOTS

Stream Mach number, M_o	ΔM_{max} over $\frac{2}{3}$-jet-diameter test region
0.856	±0.006
.907	.007
.934	.007
.949	.008
.978	.008
.999	.007
1.028	.004
1.048	.004
1.069	.009
1.112	.010
1.127	.014
1.143	.012
1.164	.015
1.196	.011
1.237	.015
1.266	.018

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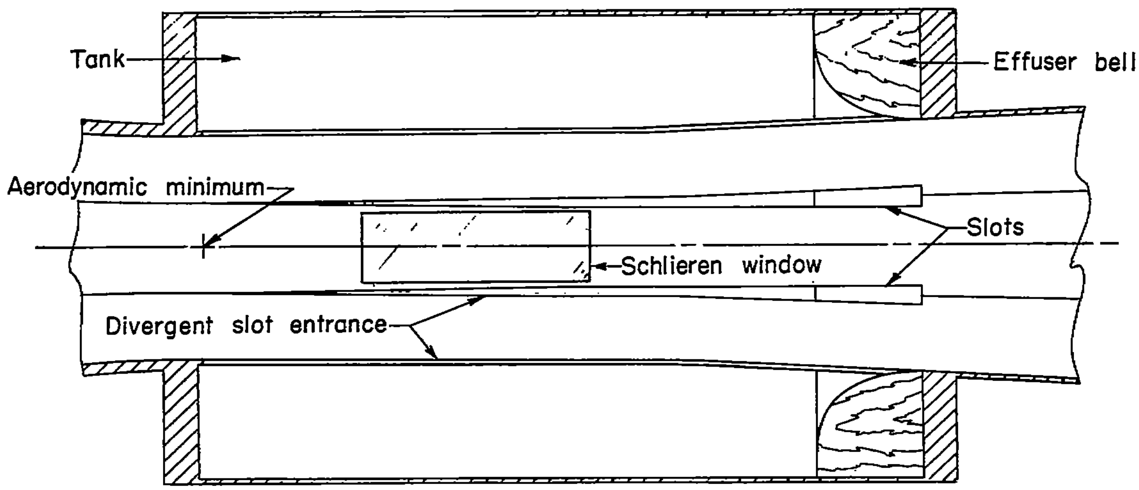
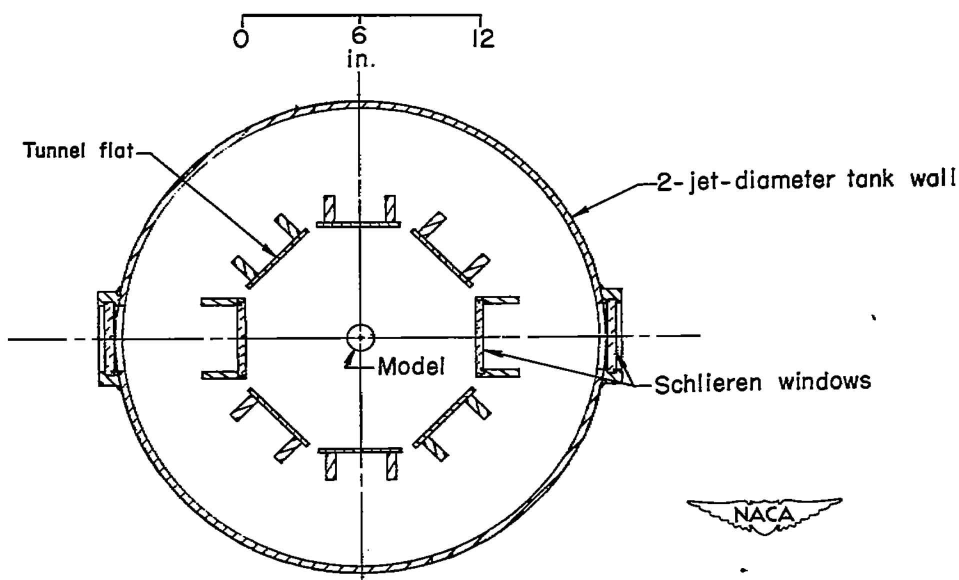
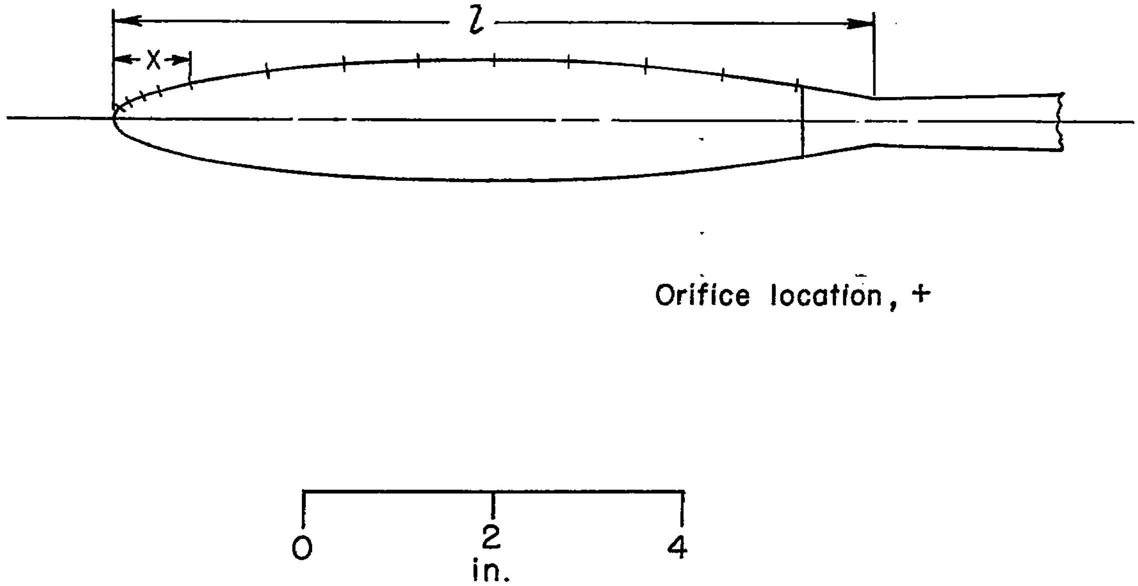


(a) Schematic diagram of octagonal transonic slotted tunnel.



(b) Cross-section view of 12-inch-effective-diameter, octagonal, transonic slotted tunnel.

Figure 1.— Transonic slotted tunnel configuration.



Body orifice locations	
x/l (℄)	x/l (℄)
.01	.40
.02	.50
.04	.60
.06	.70
.10	.80
.20	.90
.30	

Figure 2.— $1\frac{1}{3}$-inch-diameter prolate spheroid.

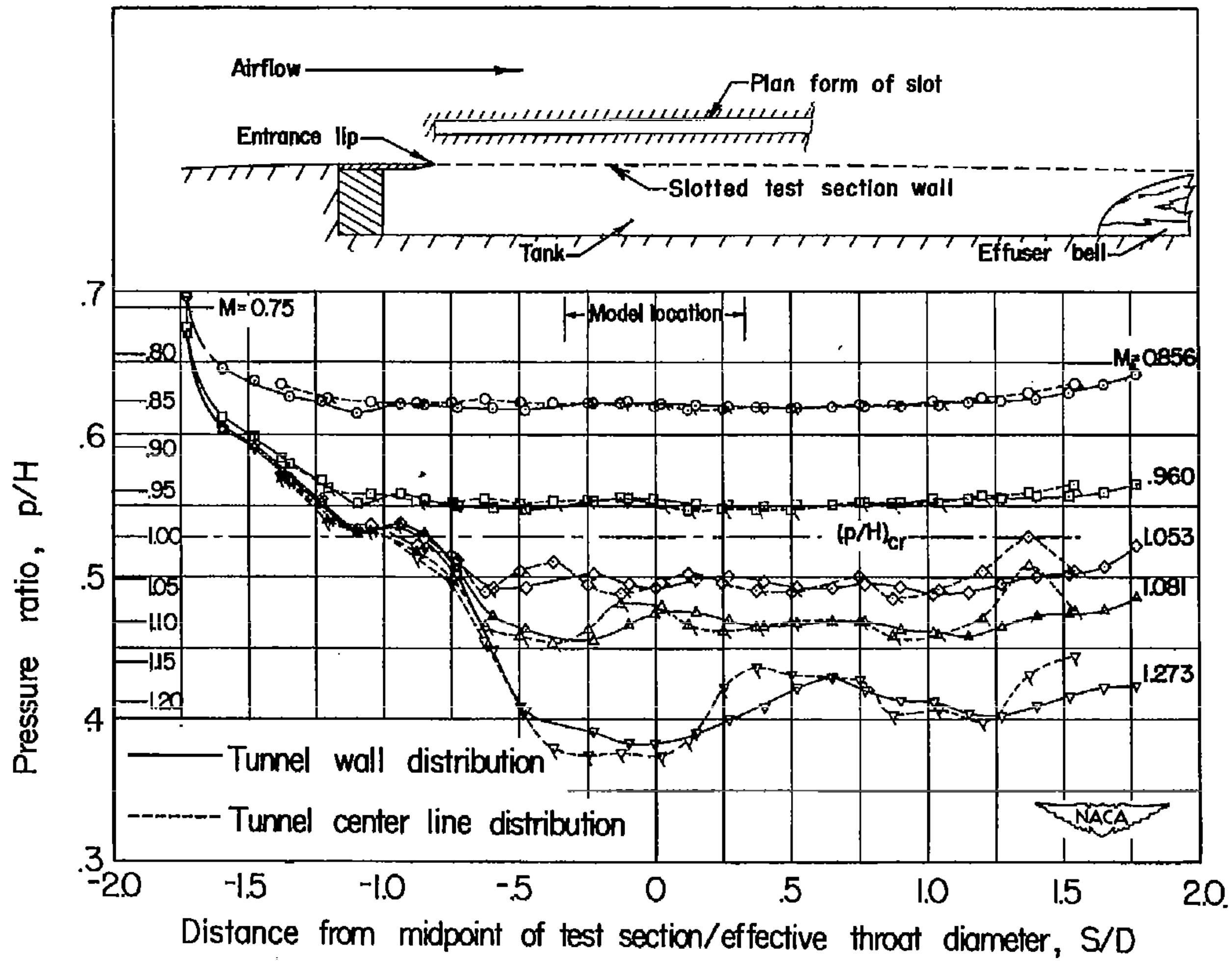


Figure 3.— Axial pressure distribution along wall and center line of transonic slotted tunnel with rectangular-slot plan form for several Mach numbers.

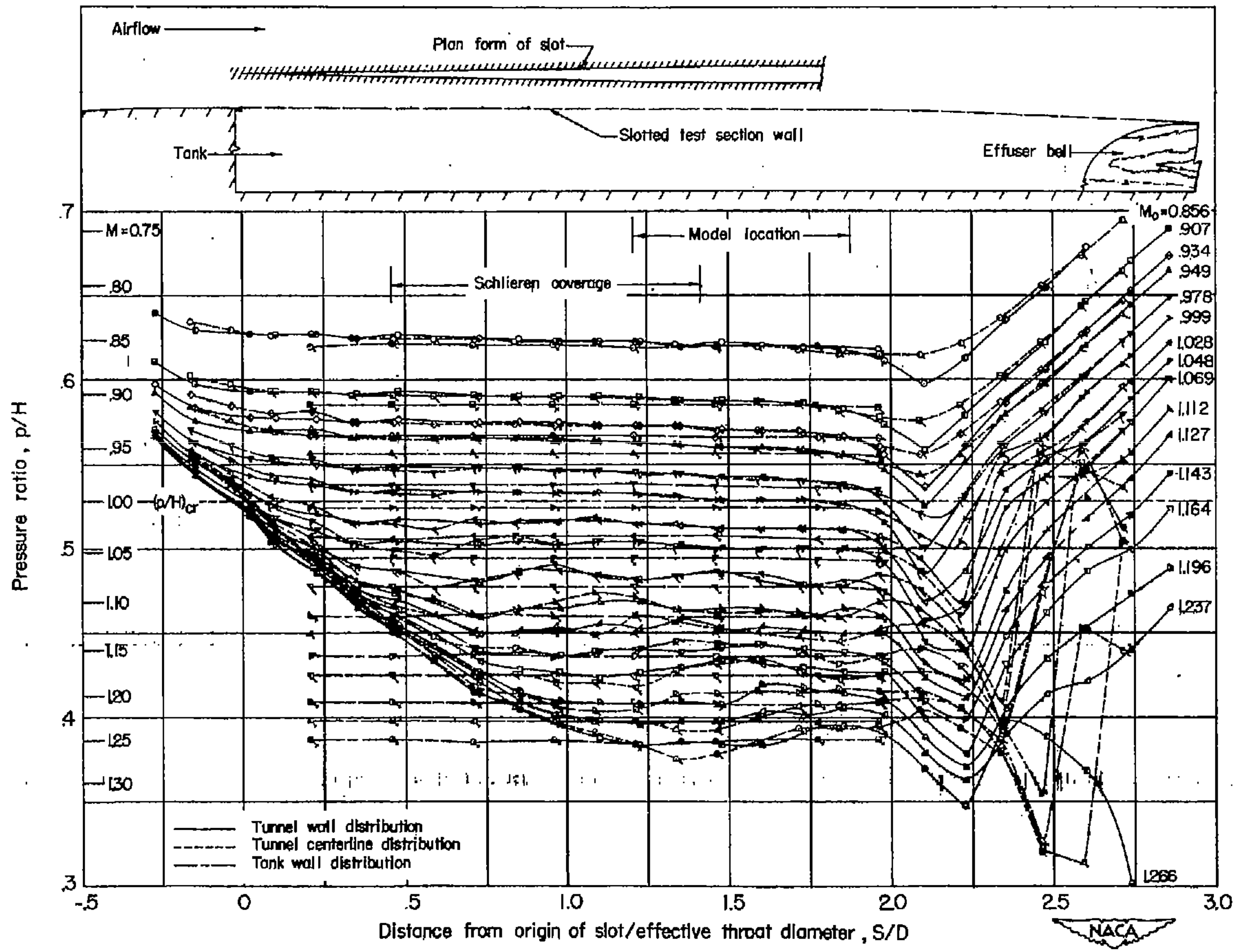


Figure 4.—Axial pressure distribution along tunnel wall, centerline, and tank wall of transonic slotted tunnel, with pointed $1\frac{1}{2}$-jet-diameter divergent slot plan form, for several Mach numbers.

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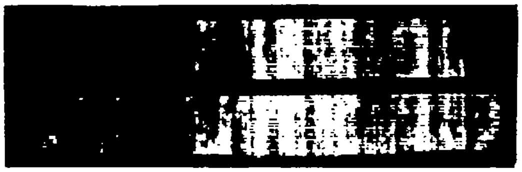
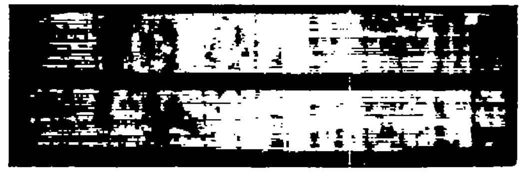
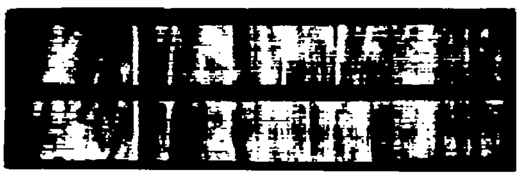


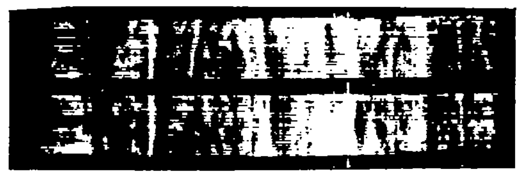
(a) $M_0 = 0.0$.



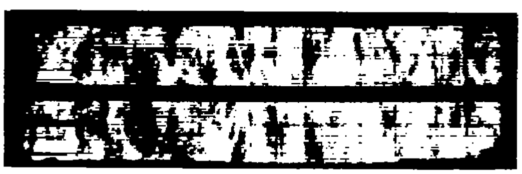
(b) $M_0 = .999$.



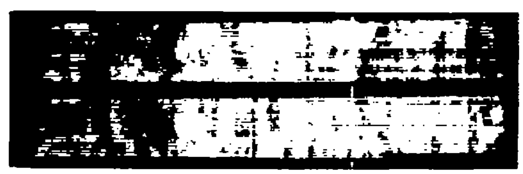
(c) $M_0 = 1.028$.



(d) $M_0 = 1.048$.



(e) $M_0 = 1.069$.



(f) $M_0 = 1.112$.

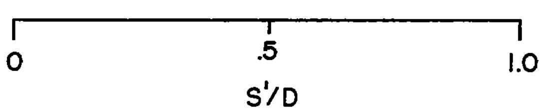


Figure 5. — Schlieren photographs of the flow in the transonic slotted tunnel, with pointed $1\frac{1}{2}$-jet-diameter divergent slots. (Position of field noted in fig. 4).

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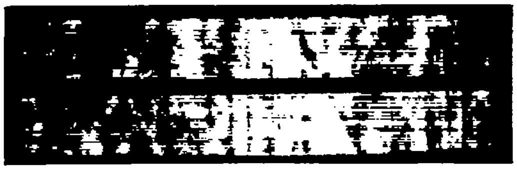
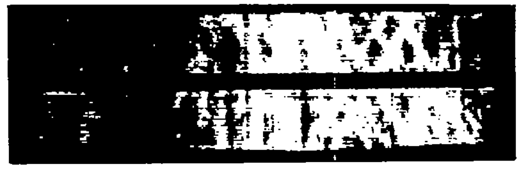
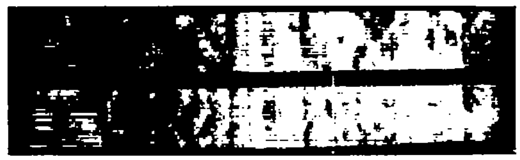


(g) $M_0 = 1.127$.

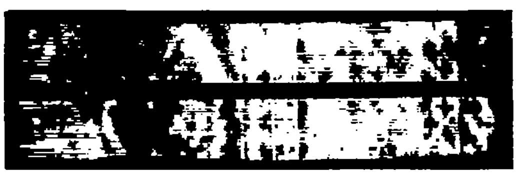


(h) $M_0 = 1.143$.

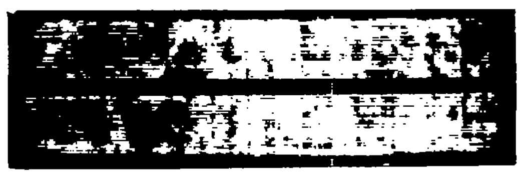
(i) $M_0 = 1.164$.



(j) $M_0 = 1.196$.



(k) $M_0 = 1.237$.



(l) $M_0 = 1.266$.

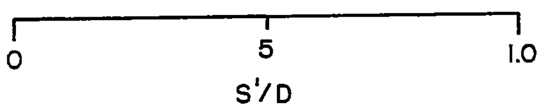


Figure 5 — Concluded.

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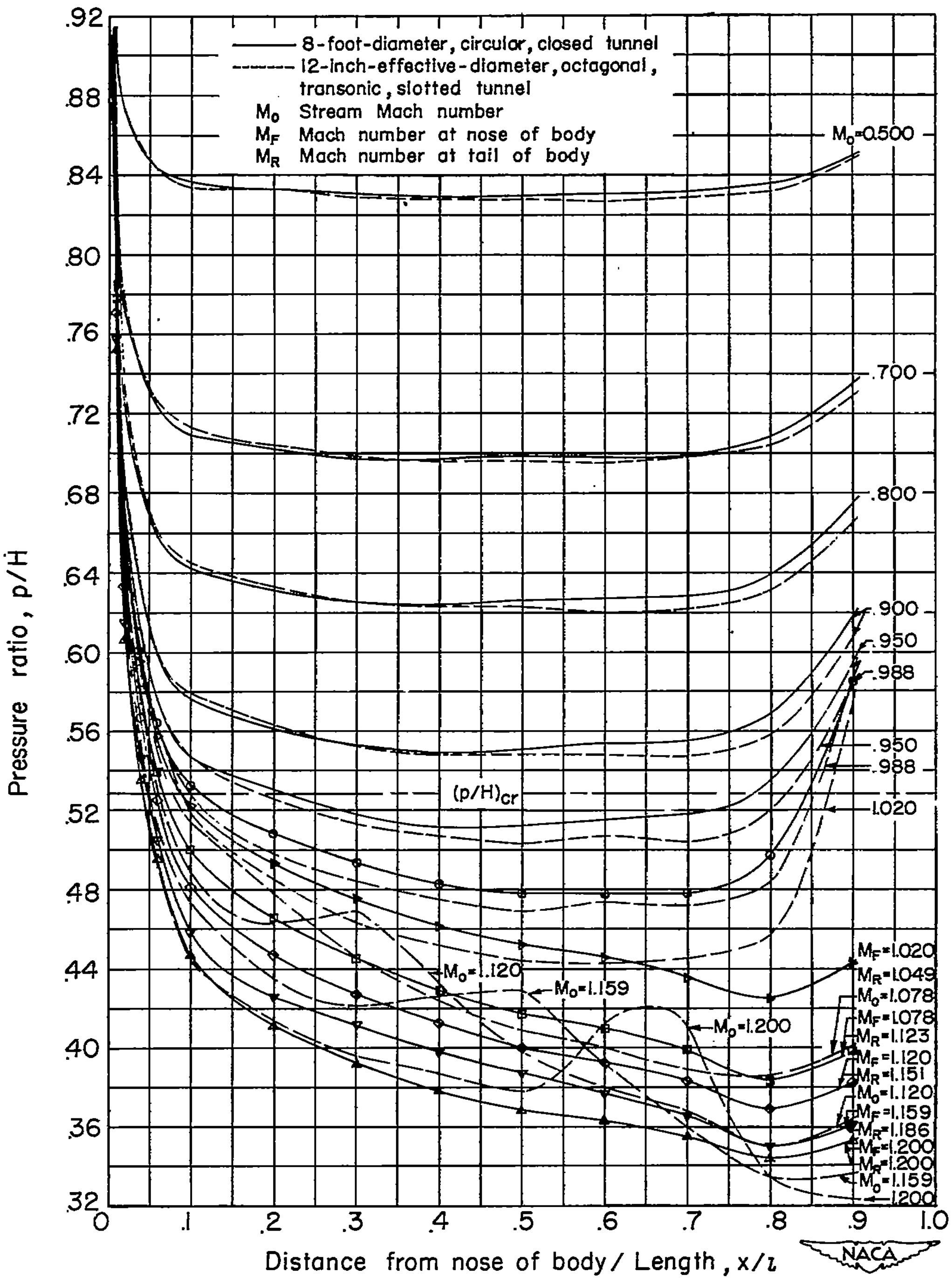

Figure 6 .— Comparison of pressure distributions over a $1\frac{1}{3}$-inch-diameter prolate spheroid for several Mach numbers in the transonic slotted tunnel with pointed $1\frac{1}{2}$-jet-diameter divergent slot plan form and in a large closed tunnel.